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DEFENSE MAPPING AGENCY HYDROGRAPHIC/ TOPOGRAPHIC CENT--ETC F/G 9/2
SOFTWARE FOR THREE DIMENSIONAL TOPOGRAPHIC SCENES, (U)

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AUTH-CARTO-5/ISPRSIV

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TITLE: SOFTWARE FOR THREE DIMENSIONAL TOPOGRAPHIC SCENES

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INTRODUCTION

The nature of the cartographer's work involves portraying geographic information about the three dimensional earth on a two dimensional medium. The topographic map represents a highly abstracted representation of the earth, and a map user needs well-defined map reading

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skills to use the map effectively. In particular, a map user needs considerable skill to read contours, visualize terrain, and orient himself with respect to the map and his surroundings. For many people, however, interpreting contours is a difficult task.

For nearly three decades, the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) and the U.S. Army Corps of Engineers, Engineer Topographic Laboratories (ETL) have been developing and using digital topographic data bases to support a variety of defense requirements. Since most of these data bases directly refer to attributes portrayed on topographic maps, both organizations are looking at ways to use digital information to supplement the map reading process. One approach is to provide three dimensional perspective graphics of digital elevation and planimetric data to the map user. This presentation on perspective graphics from digital topographic data reviews efforts by DMA and ETL to develop reliable graphic software, describes the existing production software capability at DMAHTC, and provides a projection on the future research and development efforts supported by both organizations.

DEVELOPMENT TOWARD PERSPECTIVE SCENES CAPABILITY

DMAHTC and its predecessor organizations, the Army Topographic Command and the Army Map Service, have long been engaged in efforts to develop capabilities for rapid portrayal of three dimensional topographic information. One of DMA's original products was (and still is) the well known three dimensional relief map which depicts

three dimensional characteristics of topography with a scaled model of the Earth's surface. This product gained popular use during the late 1940's and early 1950's when it was produced in quantities needed to support military needs. [3]

These relief maps were produced by completely manual procedures that called for carving into a layered wax block. Each layer of the block consisted of a laminar scaled to the thickness of the desired contour interval. The block was carved by a router which was affixed to one arm of a precision pantograph. The router was controlled by a tracing point, affixed to the other arm of the pantograph, which was used by the operator to trace the contours from a copy of the relief manuscript. The resulting contour step model was placed on a table where the manuscript contours were orthoprojected onto the model, and the steps were manually smoothed with carving tools. The carved relief model was then used to create a master mold which in turn was used to produce the plastic relief map. [7]

Based upon a need for a faster, more cost effective way of producing these relief maps, efforts were initiated in the late 1950's to develop a system to automate the process. The approach used was based upon experiments on terrain profiling and the potential of devising a method of digitally controlling the motion of a numerically controlled milling machine. The developed procedure entailed collecting contours and other key terrain data, interpolating a complete array of elevation values, and then using these values to control the motion of an automatic milling machine. [3] The key result of the effort to automate relief model making was the creation of the

capability to manipulate and display an array of terrain data. With the resulting production system developed and operating by 1965, the Army Map Service (AMS) collected data for most of the 48 contiguous United States from 1:250,000 topographic maps by 1974. [2]

At the inception of the effort, when the AMS determined that it was feasible to collect and process digital terrain data, the idea of portraying topography as three dimensional views followed. The facility to represent terrain as an array of numerical values; along with the computer's ability for rapid calculation and the advent of reliable, digitally controlled plotting devices, provided the basis for development of software for producing transformed terrain views.

One of the early operational applications of three dimensional terrain scenes was for planning the 1972 Apollo 17 Lunar Module Landing. DMA was asked to provide data around potential landing site areas for use as input into a program for generating panoramic views. The site data was digitized and processed by DMA and then forwarded to Bell Laboratories which produced the views. The software used to produce these scenes, called TOPORAMA, was developed by Bell Laboratories under a contract with the National Aeronautics and Space Administration (NASA). [6] TOPORAMA consisted of a set of programs which translated terrain data into plot lines, producing a perspective panorama and converting topographic data to a form that displayed the "terrain as it would be seen by an observer near or on the lunar surface." The objective of this program was "...to brief the astronauts on what the surface

is like," and where the "...feeling for the surface comes from thinking of the surface as consisting of two sets of parallel lines, the two sets being perpendicular to each other, and projecting these lines onto a plane or cylinder. The convergence of the projected lines results in an image similar to a photograph." [9]

Recognizing the potential use of the software for terrestrial applications, DMA obtained the software from NASA in 1974. Using TOPORAMA on the Univac 1108 computer, some demonstration scenes were produced as experimental graphics for military applications. Using the grid network as a base, planimetric features were added manually to the scene by a cartographer to produce an enhanced view of the terrain. The resulting scene shown in Figure 1 was benchmarked by DMA and ETL as the kind of graphic that could be produced in a completely automated production environment.

The TOPORAMA software had a number of restrictions on the input sequence of the terrain file and the location of the observer relative to the data. Also, the processing time to produce a scene was quite high; in fact, some versions of the software required scheduling of the computer to run for several days. DMA and ETL attempted to refine and enhance the software for general use, and to add a basic planimetry plotting capability. However, because of the inherent logical deficiencies and inconsistencies in TOPORAMA, as well as the lack of good documentation, the effort was abandoned. Additionally, it was determined after detailed examination of the program, that TOPORAMA lacked the robustness needed for production use.

DMAHTC and ETL subsequently launched a new effort in 1979 to develop software that was specifically designed for DMAHTC's potential requirements and especially suited for use with DMA digital data. This software, the Perspective Plotting Software, was developed for DMA through a research and development project by ETL. The work was performed under a contract arrangement with the Electro-magnetic Compatibility Analysis Center in Annapolis, Maryland. [4]

CURRENT PERSPECTIVE SCENES CAPABILITY

DMA Digital Data Bases

DMA currently produces a variety of digital data bases to support various requirements. The data bases vary in format from vector (digitized linework) to matrix (elevation arrays) depending on the user's specifications. In general, they are designed to coincide with the scales and specifications of map sheets produced by the Agency. Of the digital data bases produced at DMA, the most prevalent products are DMA-Standard Digital Terrain Elevation Data (DTED) and DMA-Standard Digital Feature Analysis Data (DFAD), which are produced independently for specialized purposes that do not coincide with the needs of data bases for visual displays. The data bases were chosen for perspective views, however, because of their wide areal coverage, current availability, and general acceptance.

DMA-Standard DTED is a matrix formatted product which is stored on magnetic tape as a series of geographically spaced, south-north directed profiles. Each profile record consists of

elevation posts also spaced at a specified geographic interval. The most common spacing is three arc seconds in both the south-north and west-east directions; with data coverage usually defined in terms of cells that cover one square degree. The data base is structured to cover most cells of the Earth, between 50° south and 50° north in latitude, as a matrix of 1201 columns and 1201 rows of elevation points. Because profiles of the data base are aligned to geographic meridians, which converge toward the poles, the number of columns in each cell is halved at latitudes between 50° and 70°, south and north. At these latitudes, the data base represents cells of the Earth as matrices of 601 columns and 1201 rows of elevations. At latitudes higher than 70°, the profiles are further thinned.

DMA-Standard DFAD is a vector formatted product that contains digital feature and cultural data representing point, line, and area attributes. Each digitized feature is coded under a user specified feature identifier and heirarchy, and is then sorted and stored on magnetic tape. The tape is organized into files that represent a corresponding manuscript.

Perspective Plotting Software Modules

Perspective scenes from the Perspective Plotting Software are produced to support a variety of operations. These scenes vary in detail; but requests for them usually specify the area of interest (as denoted by longitude, latitude, and map sheet designation), the observer's location in geographic coordinates,

the observer's elevation, the line of sight azimuth, the angle of view, and the locations of prominent terrain locations and features to be annotated. To create a satisfactory scene, the cartographer uses the four program modules of the Perspective Plotting Software after he evaluates and adjusts the user's parameters, the existing digital terrain elevation and feature data, and the map sources corresponding to the digital data (see Figure 2). [4] .

Both DTED and DFAD require a large amount of storage when directly read into the computer. For example, one DTED cell takes about 2.8 megabytes of disk space if it is directly loaded from magnetic tape. Searching for specified elevations and features is a time-consuming task, unless a strategy is devised to reduce search time. The Perspective Plotting Software, therefore, employs three preprocessing programs: one program to read, compress, and reformat the elevation matrix from magnetic tape to a fast, direct access disk file, and two programs to extract and sort feature data from tape to disk according to the specific needs of the cartographer.

The first adjustment the cartographer makes to the customer's parameters is the choice of the elevation matrix data resolution needed to derive a sufficiently defined fishnet grid to represent the terrain surface. The elevation matrix is processed with the Terrain Data Loader Program from magnetic tape to a random access disk file. This data can be stored at the full resolution of three geographic arc seconds; or to further compact the size of the elevation file, the data can be thinned according to the

cartographer's needs.

If the cartographer needs feature data overlays for the perspective scene, he can select a set of DFAD encoded features and build a feature library disk file with the Feature Data Loader Program. The feature library is then accessed by the Feature Data Preparation Program to build specific overlays. All data files can be saved and used indefinitely to generate a variety of scenes.

Most of the cartographer's adjustments to the perspective view enter the production flow when he executes the Perspective Plotting Program. To produce the desired view, the cartographer varies the vertical scale exaggeration, the fishnet grid detail, the declination angle, the angle of view, and the horizon distance. He can also add terrain features, denote points of interest, and mark the distance from the observer to points of interest by spacing with equidistant range lines. Since the software employs a fixed viewing frame, the view can be magnified by varying the viewing angle, thus simulating camera views with various focal lengths. Depending on the size and detail of the scene, the program is executed on a Univac 1100 series computer in batch mode or interactively on a TEKTRONIX Graphics Terminal. With the graphics terminal, the cartographer can quickly manipulate the viewing parameters of the perspective scene before he creates an off-line tape for plotting the finished graphic.

Graphic Product

The graphics produced by the Perspective Plotting Program have

four parts: a fishnet elevation drawing and spot feature legend, a general legend, an optional pie-chart orientation diagram, and optional feature overlays. At the present time, precision graphics are plotted on DMAHTC's Calcomp and Xynetics plotting systems from magnetic tape files.

The plotting software produces the fishnet elevation drawing by mathematically projecting a three dimensional surface onto a fixed, two dimensional drawing (see Figure 3a). Selected local points of interest, as defined by geographic or UTM coordinates, are annotated on the drawing and are referenced in a spot feature legend by a user defined three digit code. The spot feature legend also includes information about the heights, distances, and locations of the local points of interest, as well as a determination of whether the points are visible to the viewer. A scene title is placed above the fishnet elevation graphic.

The general legend contains the user's input parameters, the name and resolution of the data base, and a computed approximation of the size of the fishnet grid rectangles used to represent the surface in feet or meters (see Figure 3b).

The optional pie-chart diagram (see Figure 3c) displays the horizontal orientation of the perspective view relative to the viewer and the grid north represented by the included north arrow. The pie-chart also includes range lines, if the cartographer selects them on the elevation graphic.

If the cartographer has included feature overlays, up to ten separate overlays can be plotted. The overlays contain point, line, and area data which are currently symbolized with standard CALCOMP alphanumeric and special symbols. Figure 3d shows an example of a feature overlay. The linework of the overlays can be produced in various colors available on the plotters. The linework can also be used in conventional photographic processing to create color separation negatives.

The Perspective Plotting Program

When the Perspective Plotting Program constructs the perspective scene, it first reads the cartographer's viewing parameters and sets up the required geometric relationships. The software then performs the following four processes concurrently: reorganization of the input data relative to the observer's location, terrain data transformation, hidden line analysis, and plotting of feature data overlays. [1] [9]

To assist the hidden line analysis and to speed data access during the data transformations, the terrain data file is reorganized to reference four quadrants around the observer. The quadrants are bounded by divisions of the data base along lines directly south-north and west-east of the observer's location. Based upon the azimuth of the center of the view and the angular range of the view, the software determines which quadrants are visible. Because the software is limited to views less than 180 degree wide, only one, two or three quadrants can be visible to the observer.

The Perspective Plotting Program uses a basic projective transformation to construct a two dimensional drawing (x,y) of a numerically defined, three dimensional terrain model (X,Y,Z) . To derive a two dimensional diagram, projection lines, which pass through a fixed frame viewing window, are computed between the observer and points on the object. A perspective scene is constructed on the window by plotting the image that is defined when the intersections of the window plane and the projection rays are computed. For matrix formatted terrain models, the matrix elevations describe the three dimensional object as a set of rectangularly spaced posts. The perspective window image consists of projected pairs of points, representing the tops of the posts, connected by line segments. To insure that hidden terrain is not drawn on the viewing window, the software first transforms the closests pairs of post positions by determining which visible data quadrants are not partially hidden behind neighboring quadrants. Each three dimensional terrain quadrant is scanned from front to back, and the two dimensional graphic is constructed from bottom to top. As the pairs of points are transformed, a clipping function determines whether all or part of the constructed line segment is hidden.

The clipping function used by the program is a procedure that compares a transformed line segment with a special data structure. The structure contains a list of the highest, previous plotted vertical coordinate associated with each horizontal coordinate of the viewing frame. If the vertical coordinate of any part of the line segment is less than the vertical coordinate that corresponds

to the same horizontal coordinate in the data structure, the coordinate is assumed to be hidden and it is not plotted. Because the software can divide line segments into visible and invisible parts, a high degree of precision is introduced into the perspective drawing.

The program transforms feature data overlays along with the terrain data. As the clipping function examines the terrain data for hidden line segments, it identifies and saves visible feature segments. The visible features are later retrieved and plotted according to their designated overlay file. Since the cartographer uses preprocessing programs to save only data required to build transformed overlays, required search processes work quickly.

Summary of Current Capability

The efficient, modular approach of the Perspective Plotting Software enables DMAHTC to produce graphics from the computer within minutes. The interactive process also greatly enhances this capability by allowing the cartographer more immediate feedback than the original TOPORAMA process. The software can currently produce plot data for two of DMA's precision plotting devices, and these plots can be used to create photographic overlays. With the basic software operating in a manner supportive of both the user's needs and existing data bases, ETL and DMAHTC are now looking forward to developing and applying further techniques to improve graphic communication from digitally produced perspective scenes.

A LOOK AHEAD

As previously stated, three dimensional views offer an easily visualized representation of terrain. However, potential users have stated that a perspective view would be more useful with accurately placed and better symbolized planimetric feature overlaid onto the terrain surface. Planimetry adds more quantitative information to the projection, and it allows the user to quickly relate the three dimensional view to the traditional topographic line map.

Perspective symbolization gives the map user a realistic picture (model) of what an area actually looks like when locally viewed. The symbols contribute greatly to his ability to understand the contents of the scene and to plan the activities that prompted his need to view the map area. Figure 1 is an illustration of the kind of enhancements possible.

Among the problem associated with overlaying features on a three dimensional surface are drawing symbols in perspective and determining the location of hidden objects. The previous section reviewed research at ETL/ECAC that resulted in an approach to the perspective projection which efficiently solves the hidden line problem. ETL and DMA expect future developmental work to solve the problem of producing computer generated symbolization in perspective including lines of communication, such as roads and streams, and also point symbols, such as buildings and towers. Because of the large number of applicable cartographic

symbols, DMA will, from its catalog of standard cartographic symbols; select a prioritized prototype set of symbols for mechanization.

Additional future research will also expand upon methods of analytical hill shading. The approach will be based upon initial work performed by Yoeli [10]. This work employs mathematical techniques to produce shaded relief depicting terrain surfaces in three dimensions. Since this technique combines the surface geometry of the terrain and its photometric properties, the resulting scene should more closely approximate the "real" views than other techniques based solely on the geometry of projected lines. [5]

The advent of sophisticated output devices has made it practical to maximize the use of labor saving automation to produce hill shading. Additionally, the devices eliminate the traditional artistic bias that is inevitably introduced by the cartographer using conventional hill shading techniques, allowing for rapid production of uniform three dimensional shaded relief maps.

CONCLUSION

Given the assumption that digital cartographic data bases exist, and their content will improve in the future, automation should speed up the ability to produce detailed perspective scenes. We believe that graphics will prove highly useful in aiding the interpretation of the conventional topographic map. DMA and ETL

have developed a basic software to derive three dimensional scenes from both elevation and planimetric data bases. By developing and applying further symbolization techniques that are useful when presenting perspective graphics, DMA and ETL expect to help remedy basic problems with the map reading process.

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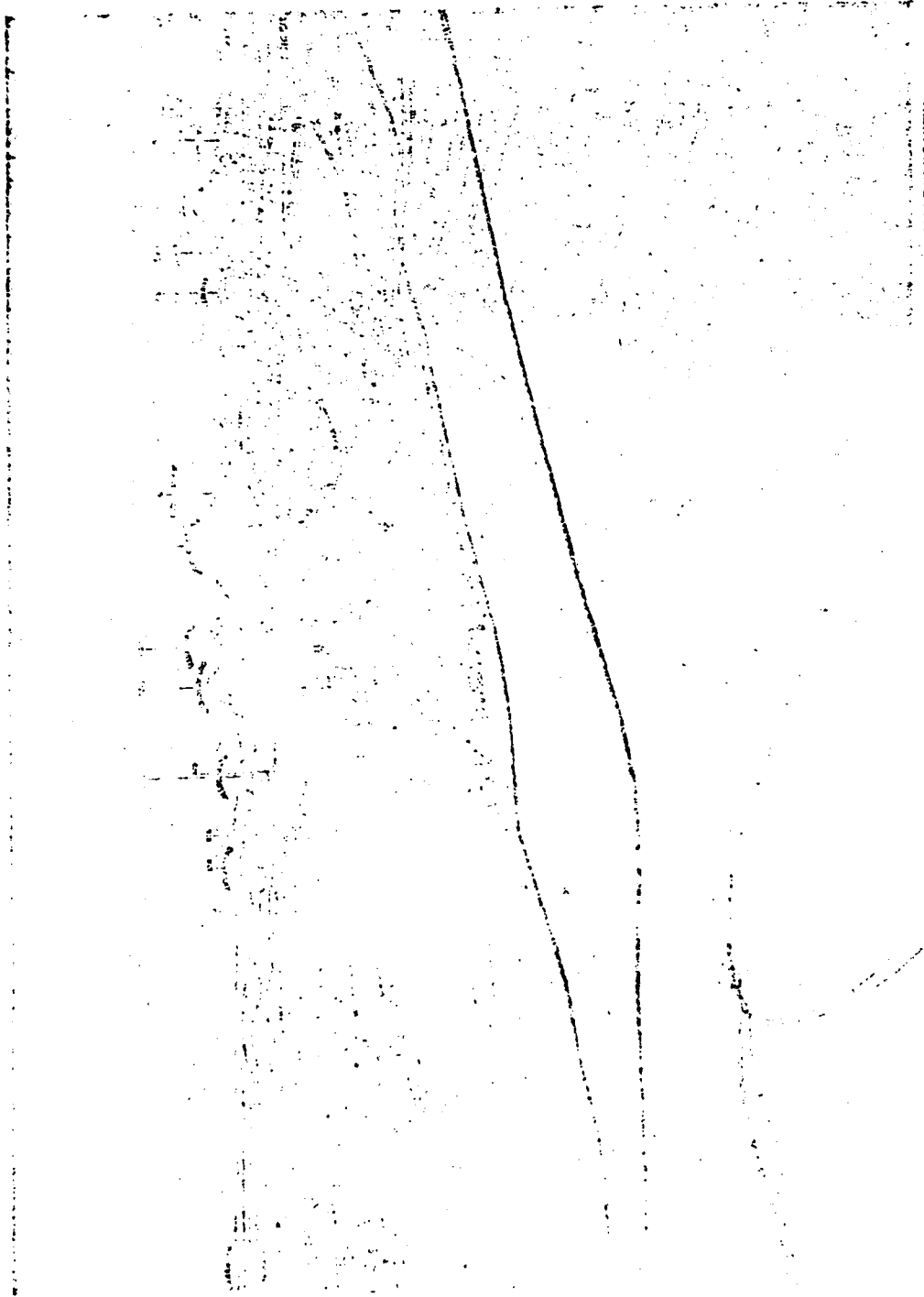
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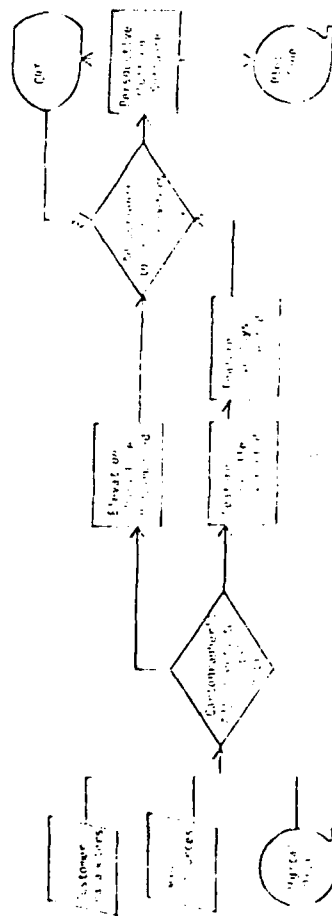
PERSPECTIVE VIEW

Map Sheet: Series 1501, Sheet W112-5
Frankfurt Am Main 1:250,000

Observer: Position-ID 6020
Elevation-500 meters
above surface

View: Primary azimuth 50°, with
field of view from 10° off
side 625m to 625m

Method: Stereoscopic



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Figure 2

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ALL DIMENSIONS ARE IN FEET AND DECIMALS THEREOF.

PERSPECTIVE VIEW

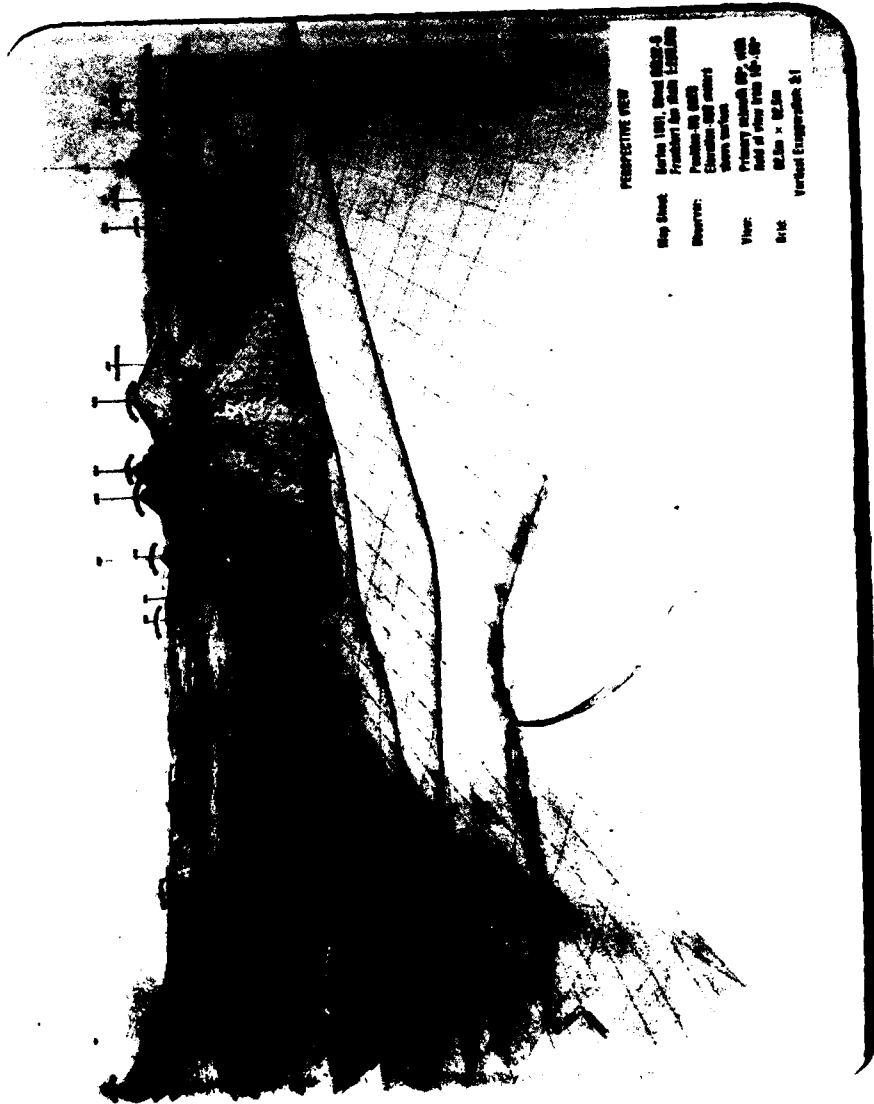
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SECTION, NORTH, SOUTH, EAST, WEST

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Figure 3a,b,c,d

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GEMINI
Transparency Mounts

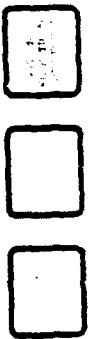


Figure 1

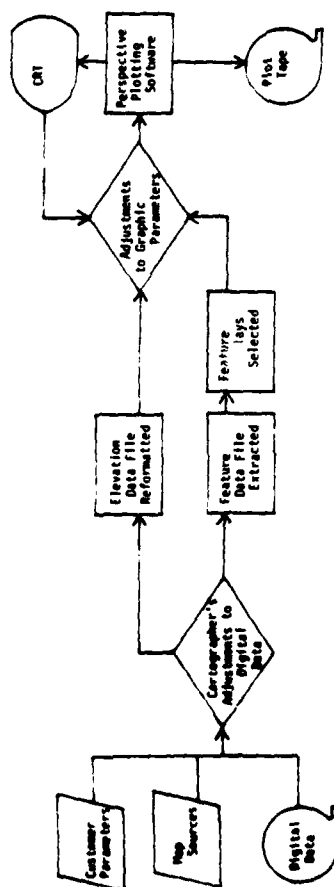
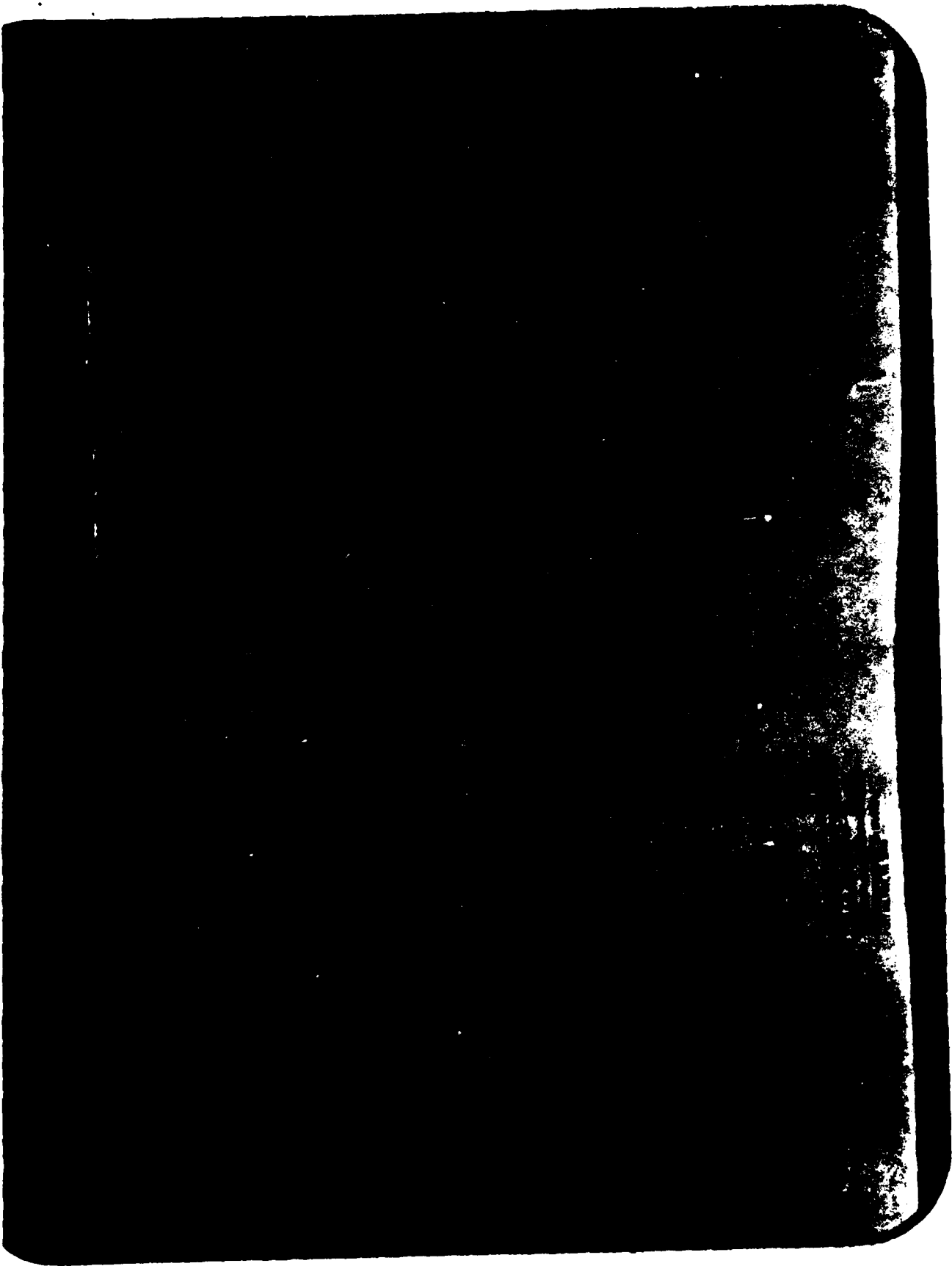


Figure 2



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Figure 2a, b, c, d

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